ENVIRONMENTAL PROSPECTS FOR THE NEXT CENTURY: IMPLICATIONS FOR LONG-TERM POLICY AND RESEARCH STRATEGIES

R.E. Munn
International Institute for Applied Systems Analysis
Laxenburg, Austria

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INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
Laxenburg, Austria

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Summary

This report examines environmental prospects for the twenty-first century, and then suggests some appropriate long-term management strategies and research priorities. A few current global trends (e.g., increasing concentrations of atmospheric trace gases, population, agricultural production) are practically irreversible over the next couple of decades due to inertias in the systems involved. However, there are bound to be nonlinearities, discontinuities, and surprises in the behavior of many environmental and socioeconomic systems. In fact, the main challenge for managers, policy analysts, and politicians is to develop strategies that are robust in response to these surprises, exploiting the opportunities as well as softening the shocks that may arise.

The main characteristics of such strategies are that they be adaptive, interdisciplinary, and cross-sectoral. As pointed out by Harvey Brooks (1986), we must avoid partial solutions that may be optimal for a particular sector or decade, but which are far from optimal for the biosphere as a whole over the long term.

Foreword

The Environment Program at IIASA is mainly concerned with long-term, large-scale (regional to continental) environmental and resource issues. In this report, Professor Munn outlines the intellectual framework, as he sees it, for this Program. I am particularly interested in two questions asked by Dr. Munn:

(1) Why should a manager, policy analyst, or politician include long-term (20–50 year) perspectives within the planning process?
(2) How should he do this, in view of the great uncertainties clouding his vision of the future?

The answer to the first question is not given until his final paragraph.

An early draft of this paper was presented at a symposium, "New Directions in International Research, Education, and Practice", held at Ohio State University, 5–6 December, 1986. The symposium was held in honor of Professor Harvey Brooks, a distinguished American and long-time friend of IIASA.

THOMAS H. LEE
Director
International Institute for Applied Systems Analysis

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ENVIRONMENTAL PROSPECTS FOR THE NEXT CENTURY: IMPLICATIONS FOR LONG-TERM POLICY AND RESEARCH STRATEGIES

R.E. Munn

1. Introduction

This report first examines environmental prospects for the twenty-first century, and then suggests some long-term management strategies and research priorities. The work draws upon studies carried out by the author for UNEP (UNEP, 1982; Munn, 1986; see *Appendix* for an explanation of acronyms) and in progress within the IIASA Environment Program. Answers are sought to the question, "*How* should a manager, policy analyst, or politician include long-term (20–50 years) perspectives within the planning process?" Because many managers will first need to be convinced of the need for considering such a long time horizon, the following question is also discussed, "*Why* should long-term perspectives be included in the planning process?" In this connection it should be mentioned that the integrating framework for the report largely corresponds to that of the IIASA Environment Program, even though other paradigms do exist. This emphasis on the current IIASA perspective should not surprise anyone.

It should also be emphasized that efforts to forecast environmental conditions in the next century would be presumptuous, even when averaged globally. So the reader is warned not to expect Nostradamus-type predictions. In fact, all that can be usefully stated concerning environmental prospects for the twenty-first century may be summarized in a few sentences:

(1) Some environmental trends are practically irreversible over the next couple of decades, due to inertias in the systems involved. These trends are discussed in Section 2.

(2) Mass and energy budget principles place long-term bounds on the sustainable use of various renewable resources. However, phrases such as "maximum sustainable yield" can be misleading (see Section 3).

(3) There will be nonlinearities, discontinuities, and surprises in the behavior of many environmentally related systems over the next several decades (see Section 4).

(4) Knowledge in the environmental sciences is exploding. The store of information has become too great for any one person to assimilate, and this has led to specialization, fragmentation, and irrelevance with respect to comprehensive environmental policy (see Section 5). The problem will become more serious in the years ahead, even with the development of complex data storage and retrieval systems.

It is clear that society needs better methods for managing the environment. These methods should include monitoring systems that provide early warning of impending change, and institutional mechanisms for responding to these changes even when their outline is perceived only dimly (see Section 6).

These themes are elaborated below. Then a brief description is given of a very practical study of future environments for the European continent being conducted within the IIASA Biosphere Sustainability Project, in which an attempt is being made to draw the various threads together (see Section 7).

2. Current Trends

Because of the inertia in many biogeochemical and socioeconomic systems, some of the current environmental trends are not likely to change very much in the next couple of decades. Of course the phrase "not likely" does not preclude the possibility of sudden changes due to war, epidemics, or technological breakthroughs.

(a) *Global increases of greenhouse-type gases*

Atmospheric concentrations of the greenhouse gases (CO_2, methane, nitrous oxide, chlorofluorocarbons, and tropospheric ozone) are increasing steadily. Even if society decided to stop increasing anthropogenic emissions of these gases, atmospheric concentrations would not level off in less than 25 years, due to socioeconomic inertias.

Examples of current trends are shown in *Figures 1* and *2*. In the first case (Harris and Nickerson, 1984), the upward trend in atmospheric CO_2 concentrations is seen to be a global phenomenon. On a longer time scale, *Figure 2* shows the rapid rise in methane concentrations that has taken place over the last 100 years (Rasmussen and Khalil, 1984).

Although the extent of climate warming that would result from increased concentrations of greenhouse gases is still controversial, a general consensus has emerged that some warming is imminent, or may already have arrived. The statement approved by participants at the ICSU/UNEP/WMO Conference at Villach, 9–15 October 1985 (WCP, 1986) includes the following:

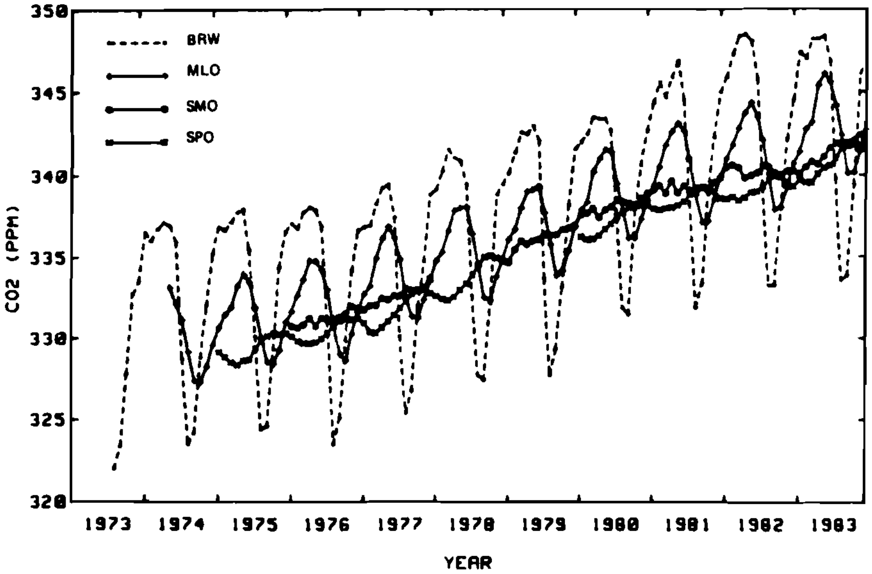

Figure 1. Annual cycles and long-term trends in atmospheric concentrations at BRW (Barrow, Alaska), MLO (Mauna Loa, Hawaii), SMO (Samoa), and SPO (South Pole Observatory)(Harris and Nickerson, 1984).

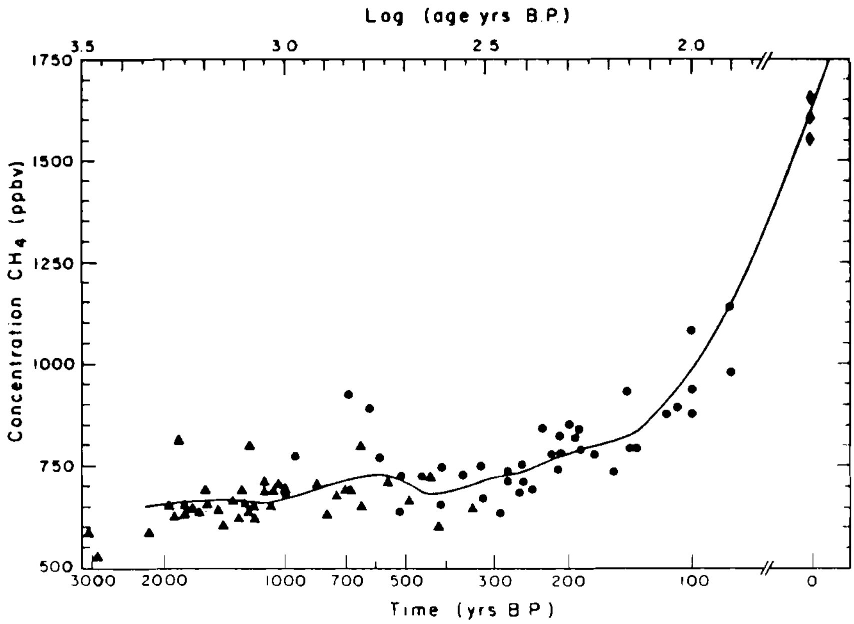

Figure 2. Methane concentrations obtained from ice cores in Greenland (circles) and Antarctica (triangles). The present concentrations of methane are shown on the right (diamonds)(Rasmussen and Khalil, 1984).

(1) Based on analyses of observational data, the estimated increase in global mean temperature during the last one hundred years of between 0.3 and 0.7° C is consistent with the projected temperature increase attributable to the observed increase in CO_2 and other greenhouse gases, although it cannot be ascribed in a scientifically rigorous manner to these factors alone. [Wigley (1986) points out that because of the large thermal inertia of the oceans, the earth is already committed to additional warming. For example, if the rise in global temperature in the last century due to greenhouse gases is assumed to be 0.75°C and if greenhouse gases were to level off miraculously, then a further warming of about 0.75°C would be unavoidable.]

(2) Based on evidence of effects of past climatic changes, there is little doubt that a future change in climate of the order of magnitude obtained from climate models for a doubling of the atmospheric CO_2 concentration could have profound effects on global ecosystems, agriculture, water resources, and sea ice.

An example of the warmer climate to be expected from the numerical models is shown in ***Figure 3***. In common with many other simulations, the warming is greatest in the polar regions in winter and least in the tropics (Washington and Meehl, 1984).

(*b*) *Trends in population, agricultural production, and energy consumption*

Population is one of the driving variables not only with respect to agricultural production and energy use but also with respect to *environmental quality*. So what can be said about population trends over the next two decades?

As part of the IIASA summer program, a group of young scientists studied several recent forecasts of global population, agricultural production, and energy consumption in the twenty-first century. An attempt was also made to produce an internally consistent scenario that fell within the range of other projections (Clark and Anderberg, 1986). The results indicate a doubling of the world's population by the year 2025 (***Figure 4***). The associated relative increases in total agricultural production and energy consumption are much larger, but the per capita increases are smaller. In this connection, the participants of a recent Dahlem Conference (McLaren and Skinner, 1987) believed that "for the world as a whole, enough land and water resources exist to meet any plausible needs of the human population over the next 50 years." Nevertheless, hunger and contaminated water will continue to be endemic in some parts of the globe.

(*c*) *Environmental quality in the developed countries*

Over the last three decades, environmental quality has improved steadily in most urban areas. However, there has has been a general deterioration in the surrounding countryside where

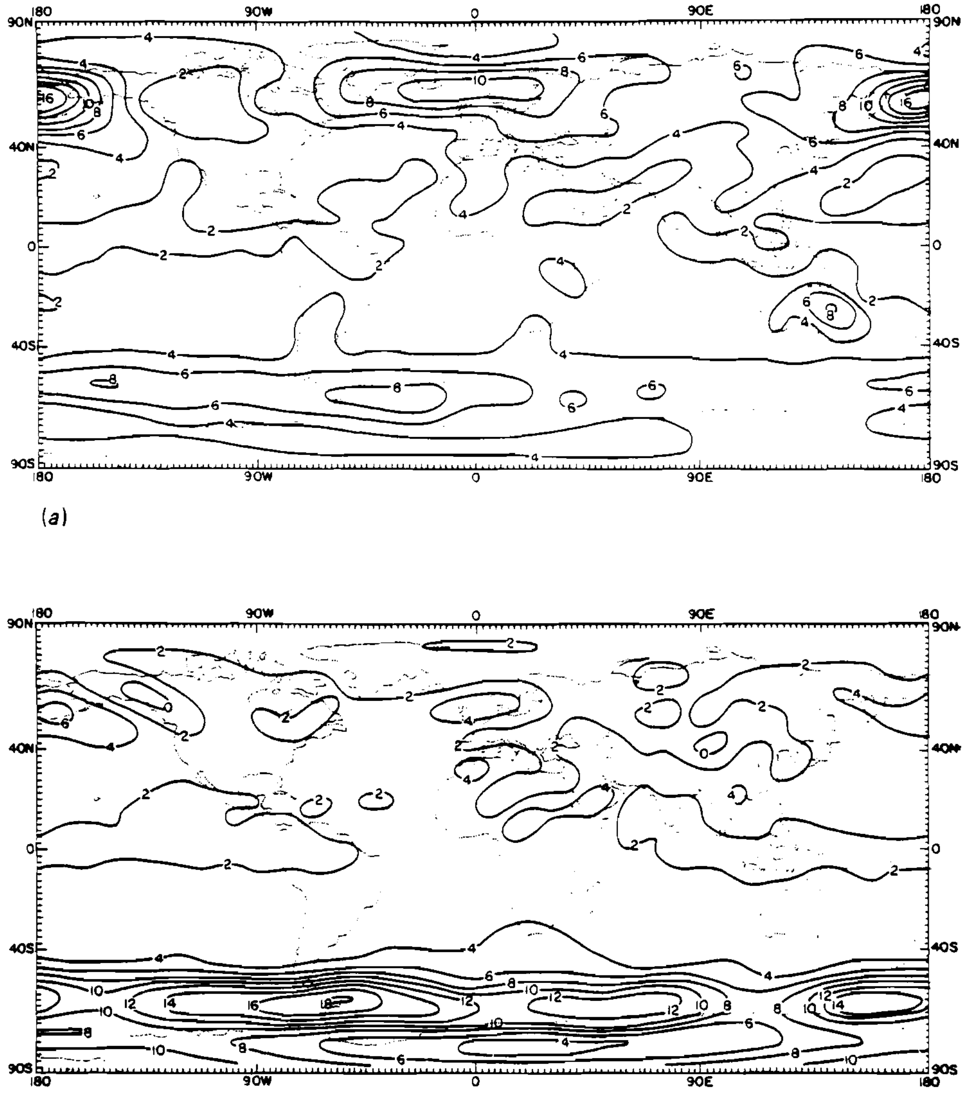

Figure 3. Geographical distribution of surface air temperature differences (deg C) for a doubled CO_2 atmosphere in (*a*) December–January–February and (*b*)June–July–August (Washington and Meehl, 1984).

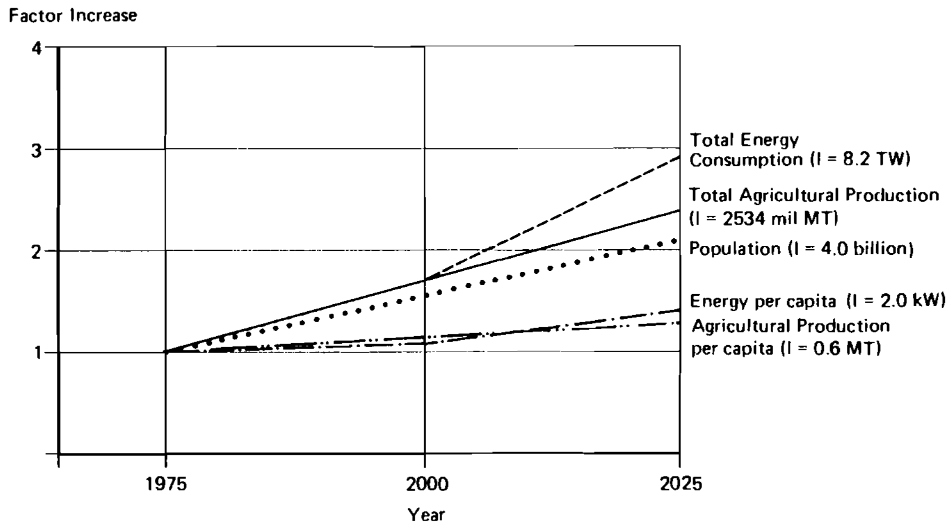

Figure 4. Consensus IIASA scenarios for global increases in population, agricultural production, and energy consumption (Clark and Anderberg, 1986)

(1) Concentrations of atmospheric ozone, sulphates, and oxides of nitrogen have increased.
(2) Agricultural wastes have been accumulating.
(3) Lake acidification has taken place in sensitive areas in both Scandinavia and North America.
(4) Forest decline has recently been observed in central Europe and eastern North America.
(5) Water quality has generally been declining slowly (see *Figure 5* for a dramatic example), although there have been some success stories. For example, water quality over the years 1974 to 1981 at more than 300 sampling sites on major US rivers has shown significant decreases in fecal bacteria and lead concentrations (Smith *et al.*, 1987).

Over the next 25 years, emission controls for sulphur and nitrogen oxides are likely to become more stringent, reducing sulphate deposition rates and arresting further lake acidification. The resulting rate of recovery of already acidified lakes is not well understood and is the subject of active research in several countries (e.g., Hutchinson and Havas, 1986). In fact, the whole field of recovery rates of many kinds of damaged ecosystems is a current topic of great international interest. Within the IIASA Biosphere Project, for example, a major symposium held in April, 1987 was entitled "Environmental Redevelopment and Restoration".

With respect to the other regional problems listed above (atmospheric ozone and oxides of nitrogen, forest decline, agricultural wastes, water quantity

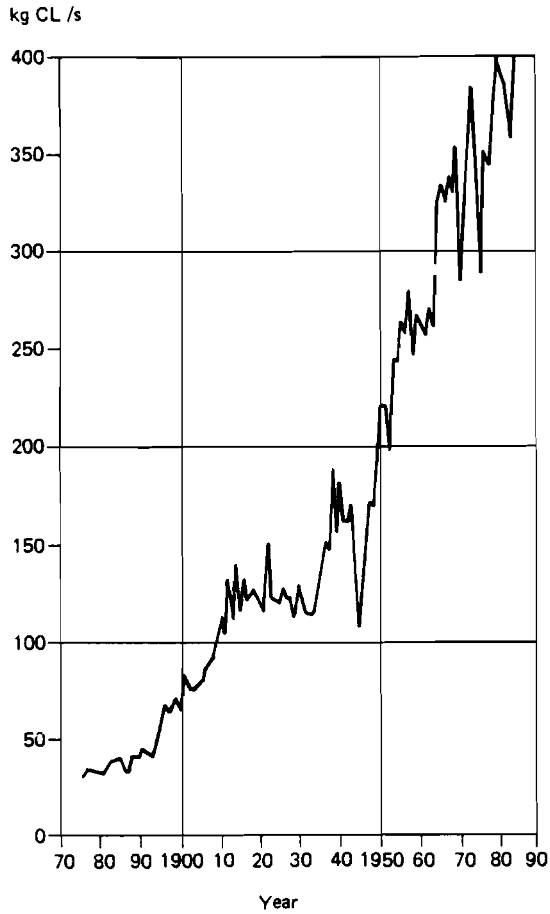

Figure 5. Variation of the chloride load of the Rhine river since 1875 at Lobith on the German–Dutch border (Volker, 1986).

and quality), conditions are likely to worsen over the next 25 years. For example, there is concern that human activities are depleting tropospheric concentrations of OH-radicals, which help remove methane, ozone, and other greenhouse gases from the atmosphere (Khalil and Rasmussen, 1985).

In connection with future trends, mention should especially be made of the important feedback effects of climate warming on environmental quality. For example, warmer and drier summers could result in an increase in the production of photochemical ozone. The effects have hardly yet been studied, although they could become significant by the year 2025. (In fact, a small study is in progress within the Acid Rain Project at IIASA to determine the sensitivity of long-range transport models to climate change.)

(*d*) *Environmental quality in developing countries*

With certain exceptions, environmental quality has deteriorated over the last three decades in both urban and rural areas (Holdgate *et al.*, 1982). For example,

(1) Air quality in urban areas such as São Paulo and Mexico City is worsening, frequently exceeding WHO health criteria.
(2) In semi-arid regions, fuelwood gathering, overgrazing, desertification, and salinization are major concerns.
(3) In the humid tropics, deforestation continues (Gwynne *et al.*, 1983), although some ecologists do not class deforestation *per se* as deterioration.
(4) Water quantity and quality continue to be serious issues.

The problem of meeting the basic needs of millions of people in developing countries will not easily be solved. The mid-term and probably also the long-term outlooks are therefore very bleak, indeed.

3. Ecologically Sustainable Development of the Biosphere

In the mid-1970s UNEP introduced the term *outer limits*, which was intended to suggest that overexploitation of Planet Earth would lead to ecological disaster over the long term. A phrase with a rather similar but subtly different connotation – *maximum sustainable yield* (MSY) – has been used for many years with respect to a single resource, such as a fishery or forest. In this case, there is the implication that a renewable resource may be safely harvested up to a certain level. As has been emphasized by Walters (1986), however, this is a dangerous strategy because "the exploitation rate that produces MSY is likely to be near a cliff edge, with slightly higher rates driving the stocks toward extinction". MSY is not an easy quantity to compute and, in any event, it varies with externalities and can decrease appreciably following the occurrence of a rare event, such as El Niño in the case of fisheries or prolonged drought in the case of productive rangeland. Two related terms are: *assimilative capacity*, e.g., of a watershed with respect to sources of pollution; and *carrying capacity*, e.g., of an area with respect to the population (usually human) that it can sustain.

IIASA has made a series of important contributions to the science of renewable resource management, e.g., Holling (1978), Walters (1986), Clark and Munn (1986), and a current IIASA project within the Environment Program entitled *Ecologically Sustainable Development of the Biosphere*. These words are used at IIASA in the following ways:

(1) *Development* is intended to convey the idea that the biosphere can be made more productive, or "better" in some sense; the word therefore involves a value judgment. Development often implies *structural change* as opposed to *growth*. The rate of development is not constant, but depends on ecological, political, cultural, and technological factors.

(2) *Sustainable* refers to the maintenance or enhancement of a process or activity over the long term (WCED, 1986). The words *sustainable* and *development* may seem to be contradictory (O'Riordan, 1985). However, one need not be overoptimistic to believe that development can be sustained through technological innovations and improved management strategies.

(3) *Ecologically sustainable development* implies that biosphere development can be sustained through the wise use of sound ecological principles that maintain or improve biosphere resilience; possible examples of policies with the opposite effect include the promotion of monocultures or massive applications of fertilizers, herbicides, pesticides, lime, or energy. In fact, the modifier *ecologically* is not really necessary and has been added for emphasis.

(4) Thus, *development* is *sustainable* over the long term only if it is *ecologically sustainable.*

Biosphere development could not, of course, be sustained in a Malthusian world. In fact, mass and energy budget principles seem to place long-term bounds on the number of people that could be supported on Earth or in a region. In principle, it ought to be possible to estimate the increases in agricultural production and energy consumption required to sustain any given number of people, e.g., 100 billion for the globe or 30 million for Mexico City. However, there are important environment–resources–population–technology interactions. Thus, for sufficiently large increases in population, environmental quality and the stock of renewable resources would both decline. The extent and rapidity of these declines are difficult to estimate, particularly because new technology unforeseen today could provide a counterbalancing influence.

It is appropriate to emphasize the need to maintain the sustainability of Planet Earth. However, the task of establishing *outer limits* is very difficult, indeed, because of (a) the patchwork-quilt, nonhomogeneous nature of the Earth's surface; (b) the existence of interactions and feedbacks among species and communities of species; and (c) nonlinearities inherent in geophysical, ecological, and socioeconomic systems. It seems that, although we may be able to describe internally consistent environmental futures, we are as yet unable to quantify the outer limits in any useful way. However, work is in progress within the IIASA Biosphere Project to begin ranking the various pressures being placed on the biosphere with respect to their potential long-term consequences.

4. Nonlinearities, Discontinuities, and Surprises

Computer outputs from large simulation models are often smooth curves (linear, exponential, having decreasing slopes, etc.) as functions of time. In the case of complex biogeochemical and social systems, these curves are not likely to represent real behavior, except as approximations over small segments of time. Complex systems usually contain positive feedbacks and nonlinearities, some of which may ultimately produce discontinuities. There are, of course, many negative feedbacks that keep system behavior within tight limits for long periods of time. For example, the average temperature of the Earth has remained within narrow bounds over several centuries. This, however, does not ensure that such a condition will continue over a time period even as short as the next century. Here it should be emphasized that it is very difficult to predict a runaway excursion, although in retrospect it is usually easy to explain.

Associated ideas are those of *resilience* and *vulnerability*. Motivated by the ecosystem studies of C.S. Holling (1973) at the University of British Columbia and at IIASA, ecologists have become very interested in discontinuities. Some of these ideas have even been applied to socioeconomic systems, e.g., Burton (1983) has discussed the vulnerability and resilience of cities. One of the central themes of resilience is that although an ecological or social system may seem to be in a steady state, it may shift to a new steady state if perturbed sufficiently by a large shock. Resilience is difficult to quantify, although qualitatively,

(1) Patchiness is characteristic of a resilient forest (Holling, 1986).
(2) Societies in the process of losing their traditional skills have little resilience (Burton *et al.*, 1977).
(3) An increase in the reliability of a managed system often leads to a decrease in resilience (Hashimoto *et al.*, 1982; Timmerman, 1981, 1986).

Brooks (1986) has given some examples with respect to technological developments.

In the case of social systems, resilience may be affected by changing values, norms, and aspirations. It could in fact be argued that, before beginning a consideration of possible environmental futures, it is necessary to reflect upon the changing attitudes and goals of society over the coming decades. This is a missing link in many such studies.

There is no doubt that the incorporation of nonlinearities or surprises into simulation models is very difficult. However, models that do not have these features are not very useful as management tools. An approach involving policy exercises that may bypass this difficulty is described in Section 7.

5. Usable Knowledge

The knowledge base in the environmental sciences is very large and growing rapidly. When applying this knowledge to an emerging, poorly focused issue, however, the available information is often largely irrelevant. Not only are there important knowledge and data gaps, but also the existing information is compartmentalized within a traditional framework that cannot easily be mobilized to meet the new paradigm. The problem arises partly because of the separations that exist among scientific disciplines, both in the universities and in government research institutes. The theme of the UN Stockholm Conference on the Human Environment in 1972 was Barbara Ward's "Only One Earth". Yet the Conference recommendations were mainly concerned with sectoral subdivisions of responsibilities to WMO, WHO, FAO, UNESCO, etc. - the work to be coordinated by a small new body subsequently called UNEP. It is indeed surprising that UNEP has achieved so much; see Holdgate *et al.* (1982).

The experience in IIASA, SCOPE, and other such international organizations is that scientists in the same discipline coming from different countries and speaking different languages understand each other. Scientists from different disciplines often have great communication problems, even when working in the same university.

A related problem is that the perception of an environmental issue may vary from discipline to discipline; the priority given to an issue may thus vary greatly. These perceptions may also differ from those of policy-makers or the media. The emergence of McLuhan's "Global Village" has resulted in the phenomenon of "Trial by Television" (O'Riordan, 1984), in which the opinions of millions of persons are shaped by inadequate and often incorrect reporting of environmental issues, such as the Chernobyl accident or the siting of toxic waste facilities.

At the World Climate Conference in Geneva in 1979, Professor Fedorov of the USSR suggested that serious international tensions could arise if several successive years of poor harvests were to occur in North America and Eastern Europe, and if American and Soviet climatologists disagreed on whether the poor harvests were the result of a short-term climate anomaly or were due to a permanent shift to a warmer Earth. In this particular example, the WMO has an important role to play in reaching international consensus. More generally, there is a real need to improve current methods of global environmental management. This is the subject of the next section.

An important final point is that the knowledge needed for policy analyses is usually quite different from that provided by scientists. Within the IIASA Environment Program, special efforts are being made to overcome this difficulty: most of the Projects are *policy-driven*, with the goal of providing what Lindblom and Cohen (1979) have called *usable knowledge*. In the case of the Acid Rain and the Large International Rivers Projects, this knowledge is in the form of user-friendly decision support systems, in which the outputs of some very complex environmental models are displayed in useful ways; see, e.g., Alcamo *et al.* (1985).

6. Environmental Management

A central theme of this paper is that surprises are certain to occur, and that long-term environmental management ought to concentrate on the development of strategies to cope with the unexpected. Surprises can be grouped into three main types:

(1) Those with historical analogues, whose main properties and characteristics are reasonably well understood but whose occurrence can not be predicted, e.g., tornadoes, earthquakes, and hailstorms at a particular place and time; or the death of a particular individual from a particular cancer.
(2) Those that have never happened, but whose possible occurrence has been the subject of considerable discussion and simulation modeling, e.g., greenhouse warming, stratospheric ozone depletion.
(3) Those that have never happened and have never been seriously considered as remotely possible at the time they occurred, e.g., the New York State power blackout, the "hole" in the Antarctic stratospheric ozone layer.

Brooks (1986) has produced a typology of surprises that is not entirely dissimilar. Brooks makes the important additional point that surprises may trigger other surprises, e.g., an unexpected drought could turn rangeland to desert. The challenge to policymakers is to recognize that a seemingly steady-state condition may hide instabilities that could become important if the system were subjected to a sudden shock. In yet another taxonomy of surprises, Timmerman (1986) emphasizes that some kinds of surprises are of central importance, "revealing essential characteristics of system dynamics".

Management strategies for coping with Type (1) surprises are reasonably well developed, particularly with respect to the design of structures. The first step is to define an acceptable level of risk – the most difficult task! Then extreme value theory (Gumbel, 1958) is applied to ensure that the structure will survive a shock of a given magnitude for a given return period.

More generally, the following checklist summarizes the several strategies that have been applied to cope with Type (1) surprises (Munn, 1986). Some practical examples are given in brackets.

- □ Removal (banning of hazardous substances)
- □ Avoidance (siting towns on high ground to avoid floods)
- □ Risk protection (strengthening the foundations of buildings in earthquake zones)
- □ Mitigation (crop insurance; the International Red Cross)
- □ Learning by experience (information retrieval systems)
- □ Diversification (multiple crops; staggered planting)
- □ Small is beautiful (construction of several small dams rather than one large one)
- □ Saving for a rainy day (world food banks; conservation)
- □ Self-sufficiency (recycling; ecodevelopment)
- □ Development of an ability to react rapidly to surprise (adaptive impact assessment; resilience; keeping options open). [This has been the subject of important IIASA studies over the last 10 years. See, for example, Holling (1978), Walters (1986).]

- Development of early warning indicators (World Weather Watch; tidal wave forecasting systems)

These strategies are not new, and in fact can be traced back to nursery rhymes, fables, and proverbs, e.g., "Waste not, want not" (Munn, 1986).

With respect to Type (2) surprises, the strategies listed above should still be appropriate. However, because of a lack of historical precedents, governmental and intergovernmental bodies are unlikely to take anticipatory actions. In addition, the people most affected sometimes lack viable options; Glantz (1981), for example, suggests that the Peruvian fishery fleet was so overcapitalized at the time of the El Niño 1972–1973 decline of the anchovy population that operators had no option but to continue harvesting.

In some of his current reflections at IIASA, Clark (1985, 1986) has used the climate-warming issue to illustrate his belief that Type (2) surprises should be re-examined within a risk assessment framework. The idea of a 2° C global warming predicted by numerical models is not very surprising anymore. However, the 2° rise is a maximum likelihood estimate and, as pointed out by Dickinson (1986), the models also suggest a 1% probability of a 9° C warming by the year 2100, and a 0.1 to 0.01% probability of 15° C warming. In either case, the Earth's climate would be as warm as that of the Cretaceous era 100 million years ago. Such an occurrence would indeed be a surprise! In this connection, a large hydroelectric dam has about the same probability of failure by the year 2100 as that of an atmospheric warming of 9° C, and it is not global in impact. Clark's general conclusion is that "this assessment jars common sense, which is exactly why careful risk assessments of the CO_2 question and the possible social responses to it should become a priority task".

With respect to Type (3) surprises (totally unexpected), the last two strategies on the list above should, of course, be pursued, but in association with concerted efforts to understand better the world around us, particularly in terms of integrated, conceptual frameworks of the global environmental systems. In particular,

(1) We need better understanding of the world's major geophysical, ecological, and socioeconomic systems. The recently established ICSU Program, IGBP – Global Change, will contribute significantly to our knowledge of the linkages between geophysical and ecological systems, and should be supported.

(2) We need to improve the ability of global monitoring systems to provide early warning of potential problems. Major attention is being given to this question within the IIASA Environment Program.

(3) We need to keep options open. Carl Walters (1986, p. 351), in his IIASA book on *Adaptive Management of Renewable Resources*, suggests that we also need to seek imaginative new options, always expecting and profiting from change.

7. The IIASA Case Study of the Future Environments for the European Continent

One of the current activities at IIASA, and one of its most important undertakings to date, is the *Study of Future Environments for the European Continent* being carried out within the Biosphere Project by William Clark, William Stigliani, and colleagues. Europe is defined as extending from the Atlantic to the Ural mountains; the time span is 200 years into the past and 100 years into the future. The study has three related objectives:

(1) To characterize the large-scale environmental transformations that could be associated with plausible scenarios of Europe's socioeconomic development over the next century.
(2) To identify the research and monitoring priorities for improving the scientific community's policy-relevant assessments of the environmental transformations characterized in (1).
(3) To assess the implications, feasibility, and limitations of alternative technological and institutional initiatives that might be undertaken in an effort to manage long-term, large-scale interactions of Europe's future development with its natural environment.

A unique feature of the study is the inclusion of "surprise-rich" futures and of associated early warning monitoring systems. The objective of the study is not to predict the future, but to design robust management strategies, e.g., ones that keep as many options open as possible.

The Case Study is proceeding as follows:

Task 1: Preparation of socioeconomic development scenarios.
Task 2: Estimation of environmental impacts of these development pathways.
Task 3: Estimation of management strategies that might realistically change the course of the development scenarios given in **Task 1**.
Task 4: Analysis of discontinuities and surprises.
Task 5: Policy exercises, in which small groups of senior policy advisors, scientists, and development experts work through various plausible scenarios of "collisions between human development and the natural environment" (Stigliani, 1987).

The policy exercises are a central methodological objective of the Case Study.

The Case Study is still at an early stage, and staff are still being recruited. It would therefore be inappropriate to discuss results. However, it should come as no surprise that the usual issue-by-issue sectoral approach has been replaced by an integrated regional assessment in which the impacts of concurrent changes in several environmental and socioeconomic factors are examined, e.g., climate, acidity, oxidants, toxic materials, major nutrients, ionizing radiation, primary productivity, species diversity, land use patterns (and interconversions), and water use and availability. The surprises to be incorporated into the scenarios are still being developed (workshops on surprises were held in Sweden in 1986 and at IIASA in June 1987); see Hägerstrand (1987), for example.

8. Conclusions

An implicit conclusion to be drawn from this paper is: "Stop trying to predict the problem-of-next-year." That is futile! Instead, try to develop scientific and institutional frameworks within which a suite of issues, some unexpected, can be managed. As recent examples of new priorities and issues:

(1) In early 1986, the environmental problem-of-the-year shifted from *acid rain* to *toxic wastes* in both the USA and Canada.
(2) In 1985, a so-called "black hole" in stratospheric ozone was discovered, occurring in Antarctica in October (Farman *et al.*, 1985).

In both cases, there has already been a significant shift in budget allocations.

Over the last 15 years, a broad integrating framework involving *biogeochemical cycling* has been emerging, within which a number of environmental problems can be viewed – acid rain, greenhouse-gas climate warming, stratospheric ozone depletion, and land degradation by fertilizers (Tolba and White, 1979). The hypotheses that have been proposed will be tested within the ICSU IGBP Program (Global Change).

Here it should be emphasized that we need not only an integrating environmental framework, but also an integrating institutional framework. As emphasized by Brooks (1986), we must avoid "partial solutions" that may be optimal for a particular sector or decade, but which are far from optimal for the biosphere as a whole over the long term. Put in another way, *incremental resource management* is to be discouraged unless it is in the context of a long-term policy framework.

Additional scientific questions that should be given priority in the next decade are:

(1) What are the criteria for sustainable development of the biosphere – for both natural and managed (e.g., agriculture, fisheries) systems? This question provides a central focus for the IIASA Biosphere Project.
(2) Even before establishing sustainability criteria, what management actions can be taken to improve the resilience of the biosphere?
(3) What are the possibilities for more efficient use of natural resources? O'Riordan (1985) has mentioned several lines of inquiry that have been tried:
    (a) Improve cost-effectiveness.
    (b) Improve administrative effectiveness.
    (c) Improve energy–consumption effectiveness.

(d) Improve techniques for rehabilitating degraded ecosystems (a sub-theme of the IIASA Biosphere Project).
(e) Improve equity, i.e., social justice, with respect to present and future generations of people and of ecosystems.

These goals are not necessarily consistent with one another. Even if they were, this is quite a prescription for action over the next decade!

There remains, of course, the problem of persuading managers, policy analysts, and politicians that they should plan not just for the next two to four years, but also for the next century. Several arguments can be given for taking this long-term perspective. For one, the next century is only 13 years away! For another, the life cycle of some natural resources is of the order of decades. Foresters, for example, do not expect to harvest their seedlings in less than 25 years and, in some cases, 100 years. Third, large engineering works designed to manage the environment (e.g., flood control systems) or having the possibility of harming the environment in some way (e.g., chemical factories) typically have life expectancies of 30–75 years.

Moreover, because the past, the present, and the future are tightly coupled, environmental "surprises" often have their roots in cumulative mismanagement of the biosphere over many decades: witness the current decline in European forests, for example. Some future crises may already be in the incubation stage (Stigliani, 1987).

Thus, long-term perspectives help in developing appropriate management strategies, keeping options open, and helping in the assignment of priorities for research and monitoring programs.

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Appendix: Acronyms

FAO	Food and Agriculture Organization
ICSU	International Council of Scientific Unions
IGBP	International Geosphere–Biosphere Program
IIASA	International Institute for Applied Systems Analysis
MSY	Maximum Sustainable Yield
SCOPE	Scientific Committee on Problems of the Environment
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
WHO	World Health Organization
WMO	World Meteorological Organization